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During the quarter, eight technical reports covering six subjects were approved for distribution to the government approved list. A letter to the editor of the Bulletin of the Seismological Society of America concerning secondary P wave arrivals was also approved for publication.

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Average P and PKP Coda for Earthquakes (Report 305)

Our analysis of 418 small-event ($m_b \leq 5.8$) seismograms recorded at 17 world-wide stations, and of 148 large-event (m_b, M_s (NOS), or m_b from Pasadena or Berkeley ≥ 7.0) seismograms recorded at 8 worldwide stations and TFO indicates that coda shape is primarily a function of the arrival times and relative amplitudes of significant secondary arrivals. However, for times greater than 10 to 20 seconds into the coda, large-event codas are approximately 0.14 m_b units greater in amplitude at any given time relative to their maxima, than the corresponding relative amplitude for small-event codas. This suggests that large events are, in fact, multiple events, with the nominal period of source activity for a given sequence estimated to be on the order of 1 to 2 minutes. Correspondingly, large events also tend to be emergent, displaying a 0.2 to 0.3 m_b increase in amplitude between 5 and 30 seconds into the P-wave arrival over that observed in the first 5 seconds of the arrival. Because of their differences, large-event and small-event coda observations cannot be combined. At least two sets of coda observations are required (and are presented in the report) for coda prediction. The small-event codas are used to predict the codas for the San Fernando, California, earthquake of 9 February 1971, at 43 stations. With few exceptions, the observed coda lie within one standard deviation of the predicted coda.

An Iterative Approximation to the Mixed-Signal Processor (TR-73-7)

In this study we develop an iterative beam processor which in the limit is identical to the mixed-signal processor (Dean et. al., 1968). Assuming that two events arrive simultaneously at an array consisting of N sensors, the array is first beamed on one of the two epicenters to produce a signal estimate for this event (0'th iteration). This signal estimate is then time-shifted and subtracted from each of the original N seismograms in an attempt to remove the signal from the original seismograms. The new set of records, each containing N stripped seismograms, is then beamed to produce a signal estimate for the second event. The signal estimate for the second event is now time-shifted, subtracted from the original N seismograms, and the stripped seismograms are rebeamed on the first event. The process is repeated until differences in successive signal estimates for the desired event fall below a predetermined threshold. The iterative-beam processor has great practical (and intuitive) appeal. For seven or more elements, the iterative process converges in a few iterations requiring only a few shift and sum operations per data point, while the equivalent mixed-signal (asymptotic maximum-likelihood) processor requires a convolution for each data point.

A Source Theory for Complex Earthquakes (TR-74-4)

In this report we review several source theories including that of Haskell (1964) who developed a theory for the spectral distribution of the teleseismic compressional and shear radiation from long thin strike-slip or tensional earthquakes in a homogeneous infinite elastic space. He noted that the strike-slip earthquakes had a higher S/P (shear-to-compressional) energy ratio than was commonly observed, and speculated that most earthquakes have a small component of tensional faulting. He suggested that since tensional faults have a lower S/P ratio than do strike-slip earthquakes, a small portion of tensional cracking could dramatically alter the S/P ratio. Haskell also had some difficulty in matching the existing evidence on the ratio of short-period to long-period energy, and speculated that the fault surface might be "rough". This possibility he modeled in two ways: first, by allowing the ramp displacement function to be modulated by a sine wave, and second, by assuming that for high frequencies the fault acts as the sum of several small faults. Haskell's (1969) paper developed techniques for calculating the nearfield displacement from slip or tensional earthquakes.

In Haskell (1966) he extended the idea of a modulated ramp displacement function to a stochastic displacement function. The ensemble of displacement functions was characterized by the average autocorrelation of the ensemble. This average autocorrelation led them to an average spectrum. Haskell chose the autocorrelation function to be similar to that of the sine-wave modulated ramp function in his 1964 paper, except that it had no periodic factor, and satisfied an integral constraint resulting from the fact that the earthquake must begin and end in a state of static equilibrum.

The displacement spectrum resulting from this autocorrelation behaved at high frequencies like ω^{-3} (the spectrum resulting from the modulated ramp function was asymptotic as ω^{-4}). Aki (1967) showed that an ω^{-3} asymptote leads to predictions for the shape of the M_s-m_b curve in disagreement with observation, and chose a different ensemble autocorrelation function which yielded an asymptotic slope of ω^{-2}. (Aki's particular choice of an autocorrelation does not satisfy Haskell's criterion that the earthquake begin

and end in a state of static equilibrium. However, a different autocorrelation function, which would satisfy the equilibrium criteria, could be selected which would still result in an ω^{-2} asymptotic slope.)

Savage (1966) extended Haskell's 1964 nonstatistical theory to handle the case of a dislocation nucleating at a point in the fault plane and spreading circularly to the boundaries of a elliptical fault. (Haskell (1964) had assumed that the fault started on a line across the width of a narrow fault and propagated down the length of the fault). Savage showed that while the simple ramp displacement function yielded a displacement spectrum asymptotic as ω^{-2} in Haskell's initial line dislocation model; it resulted in an ω^{-3} asymptote when the more realistic initial point dislocation was assumed. This, he showed, was due to the fact that the radiating surface grew quadratically with time instead of linearly. This ω^{-3} asymptote was corroborated by Molnar, et. al. (1973) for cases in which the fault rupture velocity is less than the shear velocity.

Brune (1970) presented a shear wave source theory which brought together in a physically reasonable way several important concepts. He made plausible the idea that until influences from the ends of the fault were felt, the fault displacement after cracking would be a ramp function proportional to $\frac{\sigma t}{\mu}$, where σ is the stress and μ is the shear modulus. Assuming then, in effect, that the entire fault began to radiate at once, the characteristic period for the radiated shear energy became L/β, where L is the fault length and β is the shear velocity. Brune's shear wave displacement spectrum decayed asymptotically as ω^{-2}. This slope was not strictly speaking derived, but simply followed from his assumed form for the far-field solution which he chose to be in agreement with the result for an instantaneous stress pulse applied to the interior of a spherical surface (see Bullen, 1963). This, of course, is not necessarily a good model of a growing displacement nucleating at a point on the surface of a plane or spherical surface. (The fact that Bullen [1963] and Randall [1966] found corner frequencies proportional to L/β for shear and L/α for compressional motion reflects the fact that their source was assumed to act instantaneously, and not the fact that the source was distributed over a volume instead of a surface, as suggested by Molnar et al. [1973]).

In his 1970 paper Brune introduced the concept of partial stress drop, ϵ, and showed that it could lead to a spectral slope of -1 somewhere between zero frequency where the displacement spectrum is flat, and asymptotic frequencies where an exponent of -2 obtains. Savage (1972) and others have pointed out that for a long thin fault one must expect $\epsilon \lesssim W/L$ where W is the fault width due to binding of the fault at the sides.

Contemporaneous with his theoretical paper, Brune and a number of co-workers analyzed signals from many earthquakes and tried to interpret them in its light: see, for example, Trifunac and Brune (1970), Wyss (1970), Wyss and Brune (1971), Wyss and Hanks (1972), Hanks and Wyss (1972), Molnar and Wyss (1972), and Wyss and Molnar (1972). One of the most interesting findings of these analyses is that the P wave corner frequency is higher than the S wave corner frequency. Hanks and Wyss (1972) attempted to explain this fact by replacing β in Brune's (1970) theory of α, the compressional wave velocity, and appealing to the concept of characteristic wavelength. They pointed out, however, that there was not theoretical foundation for these procedures. Indeed Savage (1972) pointed out that the more precise theories of Haskell (1964) and Savage (1966) predict approximately equal corner frequencies for P and S waves, due to the fact that the corner frequencies are dominated by the duration of faulting, so long as that time is greater than L/β, and not by the length of the fault per se.

Molnar, Tucker, and Brune (1973) have reported that the P wave corner frequency is higher than that of the S wave corner for 144 aftershocks of the San Fernando February 9, 1971, earthquake. They also show by an exact solution, following Savage (1966), that the P-corner is higher than the S-corner if the strain is released instantaneously over the entire surface of a circular disk. On the other hand, if the dislocation propagates at about 0.5 times the S wave velocity then they find that the two corner frequencies are about equal. This result is in agreement with the studies of Haskell (1964) and Savage (1966, 1972).

At intermediate dislocation velocities the results of Savage (1974) show the importance of the operational definition of corner frequency. Savage (1974) shows that if the corner frequency is defined as the intersection of the

high frequency displacement asymptote with the horizontal low-frequency asymptote, then if v, the dislocation velocity, is close to the shear wave velocity the P wave corner will be substantially higher than the S wave corner. On the other hand, examination of Savage's Figures 1 and 2 shows that for the same cases the P wave corner will be on the order of only 20% higher than the S wave corner if the corners are taken as the 6dB (1.2 amplitude) points on the displacement amplitude spectrum. The identical conclusions can be obtained by examination of Figure 6 in Molnar et al. (1973). In fact, one sees there the special dangers of the asymptotic definition of corner frequencies in that for $v=\alpha$, where α is the compressional wave velocity, the intersection definition gives $f_p<f_s$ for $\Theta=85°$, an observation point near the plane of the fault. This result is easily verified from Savage's (1974) figures, and one may see also that for the 6dB corners, $f_p>f_s$. These results suggest that the 6dB corner determination is more reliable than determination by the intersection of asymptotes. It is probably just as "objective" as the intersection of asymptotes method, and is certainly not as severely affected by incorrect values of Q, a serious problem with the latter method as pointed out by Thatcher and Hanks (1973).

We show in this paper that another explanation of the $f_p>f_s$ paradox may be found by further development of Haskell's (1964, 1966, 1972) ideas that a substantial amount of tensional faulting accompanies many strike-slip or dip-slip earthquakes, and that many earthquakes are accompanied by smaller earthquakes. There is substantial evidence for this point of view in the literature. Wyss and Brune (1967) concluded that the 28 March 1964 Alaskan earthquake ruptured in a series of events; initially propagating in various azimuthal directions from the epicenter, then after a period of about 44 seconds propagating steadily to the West. They also concluded that other large earthquakes are similar in character. Trifunac and Brune (1970) found that the Imperial Valley earthquakes could be regarded as a series of earthquakes initiated along a strike-slip fault in accordance with $v/\beta\simeq.5-.6$. Kamb et al. (1971) show that the pattern of near-surface faulting for the San Fernando earthquake was very complicated, and Jungels and Frazier (1973) conclude that this complexity must be taken into account in order to satisfactorily interpret the static displacement observations. One might speculate

that if the near-surface faulting is complicated, so too must be the deeper faulting. Jungels and Frazier also require changes in dip for the fault plane. Bolt (1972) analyzed the Pacoima Dam strong motion records for the San Fernando earthquake and concluded that several "bursts" of high frequency energy were received from remote epicenters on the fault plane. Mikumo (1973) discusses the substantial field evidence for flexures in the San Fernando fault plane before adopting a plane surface for his theoretical model. Murray (1973) has concluded that the main Parkfield earthquake consisted of two separate earthquakes on two branches of the San Andreas.

It seems, in fact, that almost every carefully investigated earthquake reveals first-order departures from a plane slip fault. This, of course, is not surprising given the inhomogeneities of the real earth. Tensional sub-earthquakes must also be expected. Although a homogeneous substance may fail in shear, one must expect zones of weakness in an inhomogeneous material to "pull apart", thus introducing a tensional component to an earthquake. Alternatively, if a fault plane is curved and strike-slip movement occurs, one expects some separation on the curves.

The above remarks are not meant to deny that the best initial approximation to almost all earthquakes is slip on a plane. This is strongly implied by the numerous successful studies of long-period radiation from earthquakes based on the double-couple model. However, one might reasonably expect the high-frequency displacement spectrum asymptotes to be severely affected by small tensional sub-earthquakes.

Another puzzling contradiction between theory and observation has been the apparent S/P amplitude ratio, as observed on velocity or acceleration seismograms, of about 3/1, whereas theory, e.g. Haskell (1964), predicts a ratio closer to 10 or 20 to 1. The possibility that observations are affected by unknown variations in Q between S and P waves somewhat confuses the issue. The most reliable data is presumably that from closest in, and Trifunac and Brune (1970) show strong-motion seismograms where the ratio for the 1940 Imperial Valley subearthquakes vary between 10/1 and 1/1 with a mean around 3/1. The first six minutes of aftershocks of the February 9, 1971 San Fernando Earthquake as recorded at the Pacoima Dam strong motion instrument

also give a mean ratio of about 3/1, as we show in the original report. As pointed out by Haskell (1964), this paradox could be resolved if much of the energy around the corner frequency came from tensional faulting for which the theoretical amplitude ratio is about 3/1.

Among the important observations which a successful source theory should address are those which have grown out of the efforts to discriminate earthquakes from underground explosions. The amplitude of twenty-second Rayleigh waves plotted versus the amplitude of one-second compressional waves is known to be an excellent discriminant; see for example Evernden et al. (1969, 1971) and Marshall and Basham (1972). One of Aki's (1967) chief motivations in changing from Haskell's (1966) ω^{-3} model to an ω^{-2} model was that the latter is in much better agreement with existing M_s-m_b data. On the other hand, the "spread" in observed M_s-m_b plots is much greater than can be accounted for by sampling, measurement, and propagation errors; and therefore any single line in M_s-m_b space, such as the ω^{-2} model cannot adequately explain the data. Examples of especially discordant earthquakes that look like explosions with respect to this discriminant may be found in Landers (1972) and Der (1973). Douglas et al. (1973a) have shown that a substantial amount of this discrepancy may be explained by assuming that the earthquakes are dip-slip with a dip of 45°. This fault-plane orientation has a radiation pattern maximum for the teleseismic P radiation. Douglas et al. and Gilvert (1973) have also shown that even for point sources the average shallow shearing earthquakes will separate from explosions by approximately 0.5-1.0 magnitude units. A possible physical explanation is that if one first matches the P wave amplitudes, then for the earthquake there is ten times the compressional wave amplitude emitted as shear waves. If shear waves are about as efficiently converted to Rayleigh waves at the free surface as are the compressional waves and if the earthquake is "shallow" with respect to the Rayleigh wavelength, then one expects about ten times the Rayleigh wave from an earthquake as from an explosion of equal m_b. The same argument then suggests that for tensional earthquakes one would have only about three times the Rayleigh wave amplitude.

Anglin (1971) plotted complexity versus third moment of the observed spectrum for earthquakes and explosions and found good separation. In general

there is no physical explanation for the separation, and until one is presented, the weaknesses and limitations of the discriminant cannot be convincingly discussed. In this report we give a plausible explanation of Anglin's results by assuming that the more complex the earthquake, the more small earthquakes there are accompanying it. (A complicating point in this discussion is the idea developed by Douglas et al. (1973b) that complexity may be due to arrivals along separate low and high-Q paths.)

In this report we find that the high-frequency asymptotes of earthquakes can vary between ω^{-3} for simple earthquakes to $\omega^{-1.5}$, where the exponent is restrained only by the requirement for finite radiated energy (von Seggern and Blandford [1972] present evidence that the asymptote for explosions is ω^{-2}). We find that in the case of complicated earthquakes mixing shear and tensional sub-earthquakes, any monotonically decreasing displacement spectral shape can be attained. Savage (1972) has made much the same point, saying "the spectrum of the incoherent radiation could mask the ω^{-3} asymptotic behavior". This implies that short-period discriminants may be very unreliable in practice. However, with knowledge of the underlying mechanism it may be possible to suitably constrain the combinations of discriminants, regionalize the earthquakes, and make short period discriminants predictable and reliable.

In the original report, we develop and apply the theory, make some comparisons with previous theoretical results, and compare some results with observation.

In summary, we have developed a theory which accounts for the observed separation between M_s:m_b lines for earthquakes and explosions, and also explains the robustness of the discriminant despite wide ranges in earthquake (M_s-m_b) values. This wide range is explained as being due to the existence of both simple and complex earthquakes. One also sees that the difference (M_s-m_b) can be a good discriminant even though the slope of the earthquake M_s:m_b line is not 1.0.

The fact that P/S ratios are closer to 0.3 than to 0.03 as classically predicted, together with the observations of higher P than S corner frequency, have been shown to be related phenomena and explainable in terms of tensional subearthquakes.

A tentative explanation has been given for the success of the complexity-third moment of frequency discriminant (we might note that this discriminant is vulnerable to evasion techniques).

The results suggest that the projected intersection of the earthquake and explosion populations suggested by the data of several workers, e.g. Marshall and Basham (1972), would not occur if data at lower magnitudes were obtained. Aside from displacement overshoot, the only method for obtaining convergence of the populations would be for small events to preferentially draw relaxation energy from small source regions as in the theory of Archambeau (1968). This possibility lies outside the scope of the present theory. Mean $M_s:m_b$ regression lines appear to be somewhat lacking in physical significance. The fact that some theoretical justification can be obtained for short-period discriminants suggests that they may be relied upon in non-evasion situations if carefully regionalized and if care is taken to select paths unaffected by P wave multipathing.

Further research should aim at deciding if tensional subearthquakes really exist or are only a theoretical abstraction. Field, experimental, and numerical work should all have a place.

Investigation of the displacement time history near the front of the crack is important to see if on the time scale of interest teleseismically (or regionally for earthquake damage studies) the initial velocity is discontinuous as Brune (1970) suggested and as we have assumed. Brune (1973) has presented some experimental evidence to the contrary, but it is not completely clear that wave energy from regions of earlier movement has not slightly distorted the measurements. This question is, of course, crucial because the discontinuity in the displacement time history governs the far-field high-frequency asymptote, and any slope substantially different from ω^{-3} would require major changes in the theory.

The study of the distribution of subearthquakes is also crucial. We have assumed a delta function here; perhaps a distribution similar to that for earthquakes could be shown to be reasonable and tested. Again, both mapping of faults in the field and experimental measurements are needed.

Although we do not expect our basic results to change, it is important to replace Haskell's original solution for the simple earthquake by an exact solution for a fully two-dimensional fault plane surface for both slip and tensional earthquakes. Here Savage's (1974) lead could be followed.

As a final point, Aki (1967) and others have pointed out that for large events m_b is not a satisfactory measure of the total 1.0 Hz energy in the signal. A suitable measure suggested by Aki is the maximum amplitude in the P coda times the "length" of the coda raised to some power between 0.5 and 1.0.

A Comparison of the LASA and NORSAR Short-Period Arrays (TR-74-5)

This study compares the LASA and NORSAR short-period arrays in terms of their detection processing systems and their event summaries, for data recorded during a period of 40 days from 15 February to 25 March 1972. An overview of the worldwide surveillance performance of the combined LASA-NORSAR systems is also given.

There are two signal detection algorithms in the LASA and NORSAR Detection Processors (DP). The first algorithm checks successive signal-to-noise ratio threshold crossings by computing and comparing Short Time Averages (STA) and Long Time Averages (LTA). The second algorithm checks in successive tests the consistency of the azimuths and velocities of the arriving signal. This study showed that many of LASA/SAAC LTA measurements in the first algorithm may include part of the signal, thus lowering the reported signal-to-noise ratio. The LTA measurements in the NORSAR DP system do not inlcude any part of the arriving signals.

Either LASA or NORSAR confirmed 73% of the events on the NOAA PDE (Preliminary Detection of Epicenters) list over the data period, and 37% were confirmed by both arrays. The LASA alone reported 56% of the events on PDE list, and NORSAR alone reported 53%.

A direct comparison of LASA and NORSAR Event Summaries shows that 72% of the NORSAR published events are within LASA's surveillance range. Of these in-the-range events, 70% were confirmed by LASA. Of the unconfirmed events 11% were due to system failures, and 7% were unconfirmed by DP. Similarly, 78% of the LASA published events were within NORSAR's surveillance range. Among these in-the-range events, 38% were confirmed by NORSAR. Of the unconfirmed events 5% were due to system failures, and 45% were unconfirmed by DP. The higher percentage of NORSAR DP unconfirmed events is due partly to the high background noise of the array.

Although we do not estimate the detection thresholds of the arrays in this report, we note that the average noise on the LASA beams is about a factor of two lower than that of NORSAR. Therefore, LASA's detection threshold would be ~0.3 magnitude units lower than NORSAR's, if average signal losses were the same at both sites.

Comparison of Two Segment Maximum-Likelihood (TSML) Frequency Wavenumber Spectra with the Fast Beamed Frequency Wavenumber Spectra (FKPLOT) (TR-74-6)

The empirical comparison of the two segment maximum likelihood f-k spectra with the fast frequency domain beam f-k spectra (FKCOMB, FKPLOT) shows that the latter is more suitable for the separation of multiple signals if the amplitudes of the signals differ considerably. This advantage of the beaming process is attributed primarily to the stripping procedure, which has not been developed for the maximum likelihood spectra. The maximum likelihood f-k spectra, on the other hand, are less sensitive to the array response and easier to interpret, especially if the array used contains only a few elements, since the sidelobes of the array response are more confusing on the FKCOMB output of this case. Both processes require a good signal to noise ratio (~2) for successful application.

Composited recordings of long period Rayleigh waves recorded at LASA were utilized for the comparison using various subarray configurations and signal and noise levels.

A Study of the ILLIAC IV Computer for Seismic Data Processing (TR-74-16)

This is the first report in a series of three which pertain to our experience with the ILLIAC IV computing system. The purpose of this study was to determine the suitability of the ILLIAC computer for processing seismic data. We have done this by looking at the computing requirements of each of several algorithms; and then, by comparing these requirements with the characteristics of the ILLIAC, we investigated the feasibility of programming each of the algorithms on the ILLIAC. Finally, the procedure FKCOMB was actually coded for the ILLIAC and the program has been tested and run. FKCOMB is a long-period seismic signal analysis procedure, which is important in calculating discriminants between earthquakes and nuclear explosions; it may become an integral part of data processing on the Seismic Network. FKCOMB was chosen for this experiment because the large amount of processor time required prohibits its use in-house. Also, known results are available with which to compare the ILLIAC version.

The ILLIAC computer consists of a control unit, 64 arithmetic units or processing elements (PE), 128K 64-bit words of core, and 10^9 bits of disk storage. the 64 PE's execute instructions in lock step; i.e., they all execute the same instruction simultaneously. It is in this respect that the ILLIAC departs from conventional computer architecture.

The control unit decodes instructions and executes instructions for program control. It has 24-bit integer arithmetic hardware to calculate indices and addresses. There are four general purpose accumulators and a 64-word fast access memory in the CU, which also has access to all 128K of core and initiates transfers between core and disk.

The primary computational resource of the ILLIAC is the array of 64 processing elements. Each has complete arithmetic capabilities and can perform 2 x 10^6 multiplications per second. The capacity of all 64 PE's is about 10^8 multiplications per second. Each PE has access only to 2K of core, and has only limited capability to communicate with other PE's. Control within a PE consists of the ability programatically to disable selected PE's. When disabled, a PE's memory is protected and cannot be altered by the PE, though all other facets of instruction are performed.

The ILLIAC disk is the primary storage device. It consists of 13 head-per-track disks and two disk controllers. Together the disks hold approximately 10^9 bits. Transfers between core and disk are initiated by the ILLIAC control unit and occur in blocks or pages of 1024 words. The transfer rate is about 10^9 bits per second. Access time to any record on disk is 40 milliseconds or less. The disk can be loaded from the Tenex file system prior to program execution and unloaded after program termination. The layout of data to the ILLIAC disk is under user control and should be arranged to minimize access times during program execution.

The 64 processing elements provide the ability to perform vector arithmetic operations on 64 data elements simultaneously. Program logic generally requires that selected PE's be disabled to avoid redundant calculations if all 64 processing units are not required. In general, program execution time is decreased if disabling of PE's is avoided.

ILLIAC is able to perform approximately 100 million operations (i.e., a multiplication, addition, etc.) per second. Any procedure which requires fewer than 100 billion operations would have a running time of under 10 minutes. The setup time for an ILLIAC job is large enough to make such a run impractical. Thus, algorithms requiring very few computations or the use of a small data base with any algorithm are unsuitable for ILLIAC processing.

We conclude from this study that the ILLIAC computer when programmed to perform seismic processing on large data bases can be a valuable tool in the development of seismic event detection and discrimination procedures. It is feasible to implement some existing algorithms on the ILLIAC which are not currently used to process large data bases, or some algorithms which are proposed but not tested due to a lack of computing power. Our experience with one algorithm (FKCOMB) which is representative of seismic analysis programs shows that a major benefit of the ILLIAC to seismic processing is its ability to operate in parallel on sixty-four different data streams, thereby reducing the time required to process large data bases. Efficiently arranging these data streams for the processing element memories is an important consideration for designing any seismic algorithms for the ILLIAC.

It is feasible to program ILLIAC to perform the algorithms reviewed in this study: convolution-recursive filtering, PHILTRE, matched filtering, beamforming, and maximum likelihood f-k estimation. Since a major factor in programming any of these algorithms is the data arrangment in core, a more detailed study of the data configurations for these algorithms would be needed to optimize the use of the computing power of ILLIAC. One algorithm (FKCOMB) was studied in detail and implemented on ILLIAC IV. Data editing schemes were devised for FKCOMB which can be used with appropriate modifications for all the seismological algorithms we reviewed.

Two independent uses for ILLIAC are suggested. First, FKCOMB and other algorithms now used selectively could be run routinely on larger data bases to better provide the services they already give on conventional machines. Second, experimental methods impractical to test via conventional machines could be tested on ILLIAC. The experience of implementing FKCOMB illustrates that the design and coding of new algorithms for ILLIAC is not significantly more difficult than for serial machines. The only phase not experimentally explored by this effort are the operational problems of manipulating the large amounts of data involved in routine processing of long and short period data on ILLIAC.

To maximize efficiency, the time consumed executing analysis algorithms should be significantly greater than the time required for data editing. A combination of algorithms such as matched filtering and FKCOMB require an order of magnitude more processing time on a given memory load than FKCOMB alone, and would thereby utilize ILLIAC more efficiently.

The following points represent our findings in developing FKCOMB software on the ILLIAC.

1. Faster and more reliable network file transfer between I4-Tenex and other hosts such as UCLA, Ames, TSS and SDAC would expedite the programming and use of the ILLIAC system.

2. There is no clear preference between CFD and GLYPNIR indicated by our experiences. The possibility of implementing CFD at SDAC or upgrading service at UCLA should be investigated, and an experiment made in the use of GLYPNIR before any long range decision is made.

3. Software debugging aids presently available for ILLIAC programming are minimal. Additional debugging aids would lessen the task of ILLIAC programming. User implementation of such aids on the SDAC host is feasible though at the cost of considerable effort.

4. We estimate that the time and effort required to design and code an ILLIAC program is no more than twice that required for a conventional machine. Due to the fact that ILLIAC is not fully operational at present and the necessity to handle the large amounts of data inherent in the use of an ultrafast machine, the time and effort required currently to debug an ILLIAC program may be as much as four times that required for a conventional machine.

5. Routine processing of 24 hours of long-period seismic data is not feasible at present due to the restricted availability of the ILLIAC processor and the inability at the system to handle the large amounts of data efficiently.

Computer Program Description (TR-74-17)

In this second ILLIAC IV report we describe a preliminary version of a long period array processing package designed around the FKCOMB algorithm for use on the ILLIAC IV computer. FKCOMB is a general-purpose array-processing program that uses frequency-wavenumber analysis to produce a bulletin which lists signal detections and various statistics for each detection. Two data editing and reformatting modules prepare the seismic data for FKCOMB and can be modified for use with other seismic algorithms. Preliminary reformatting of the seismic data is performed by DEM1. The data is edited and fast fourier transformed by DEM2.

The input parameters required for operating these programs and their subroutines are described in this document.

Computer Listings for ILLIAC IV Version of FKCOMB (TR-74-18)

This is the third report in a series of three published at the Seismic Data Analysis Center in 1974, which describe our studies of and programming experience with the ILLIAC IV computer. The present report is a computer listing of the ILLIAC IV version of a scientific program called FKCOMB. The main program, FKCOMB, and two data-editing and formatting modules, DEM1 and DEM2 were written in Computational Fluid Dynamics Code (CFD); some subroutines were written in ASK code.

Letter to the Editor of BSSA

P_s and pP Phases from Seven Pahute Mesa Events

Springer (1974) observed what he thought to be secondary P-wave arrivals in teleseismic records for Pahute Mesa explosions. It was hypothesized that these arrivals may be associated with a spall-closure source (Eisler and Chilton, 1964). Spectral analysis of the P-wave arrivals for seven Pahute Mesa explosions suggests that the secondary phase due to spall closure, P_s, may be present in the records for two of the events studied.

The method we used to determine the existence of secondary p arrivals (pP or P_s) for a given event involves the analysis of null patterns in the P-wave spectra which may result from interference of the types pP-P and P_s-P. Analysis details are given by Cohen (1970) and Cohen et al. (1972).

Analysis of the records for seven Pahute Mesa events as recorded at five LRSM stations (HN-ME, KC-MO, PG-BC, RK-ON, and SV3QB) and two observatories (CPO and WMO) shows that the average P-wave spectra for two events, Knickerbocker and Rex, exhibit spectral-null patterns which may be interpreted as deriving from interference of the type P_s-P; that is, the null frequencies f_n are apparently related as follows:

$$f_n = [(2n+1)/2]\ \Delta f,\ n=0,1,2,3,...,$$

where $\Delta f = 1/\tau$, and τ is the P_s-P delay time. The spectra for the five remaining events display nulls which appear related to pP-p interference; here:

$$f_n = n\Delta f,\ n=0,1,2,3,...,$$

where $\Delta f=1/\tau$, and τ is the pP-P delay time. The relationships between null freqeuncies f_n and integers n for the seven events examined are given in the original letter.

Springer (1974) was able to obtain both pP-P and P_s-P delay time estimates for a given event because he used records taken near ground surface zero. Our results, however, indicate that at teleseismic distances, either pP or P_s, but not both, may appear as predominant secondary arrivals. That the spectra have been smoothed by averaging over a 0.15 Hz window cannot account for our inability to resolve nulls which may be associated with P_s-P interference,

for even at delay times on the order of 3 seconds, the attenuation of spectral undulations produced by smoothing is only about 3 db. Rather, it is suggested that for events for which a spall is well developed, the surface-reflected phase pP, as observed at teleseismic distances, will be weak. The reason for this is that if a spall develops, energy in the pP phase is trapped above the spall, and is subsequently released as P_s. If the spall is small or nonexistent, of course, only pP may be observed.